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## Injury prevention in team sport athletes

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## **WHICH SCREENING TOOLS CAN PREDICT INJURY TO THE LOWER EXTREMITIES IN TEAM SPORTS? A SYSTEMATIC REVIEW**

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## ABSTRACT

**Background** Injuries to lower extremities are common in team sports such as soccer, basketball, volleyball, football and field hockey. Considering personal grief, disabling consequences and high costs caused by injuries to lower extremities, the importance for the prevention of these injuries is evident. From this point of view it is important to know which screening tools can identify athletes who are at risk of injury to their lower extremities.

**Objective** The aim of this article is to determine the predictive values of anthropometric and/or physical screening tests for injuries to the leg, anterior cruciate ligament (ACL), knee, hamstring, groin and ankle in team sports.

**Methods** A systematic review was conducted in MEDLINE (1966 to September 2011), EMBASE (1989 to September 2011) and CINAHL (1982 to September 2011). Based on inclusion criteria defined a priori, titles, abstracts and full texts were analyzed to find relevant studies.

**Results** The analysis showed that different screening tools can be predictive for injuries to the knee, ACL, hamstring, groin and ankle. For injuries in general there is some support in the literature to suggest that general joint laxity is a predictive measure for leg injuries. The anterior right/left reach distance  $>4$  cm and the composite reach distance  $<4.0\%$  of limb length in girls measured with the star excursion balance test (SEBT) may predict leg injuries.

Furthermore, an increasing age, a lower hamstring/quadriceps (H : Q) ratio and a decreased range of motion (RoM) of hip abduction may predict the occurrence of leg injuries. Hyperextension of the knee, side-to-side differences in anterior-posterior knee laxity and differences in knee abduction moment between both legs are suggested to be predictive tests for sustaining an ACL injury and height was a predictive screening tool for knee ligament injuries. There is some evidence that when age increases, the probability of sustaining a hamstring injury increases. Debate exists in the analyzed literature regarding measurement of the flexibility of the hamstring as a predictive screening tool, as well as using the H : Q ratio. Hip-adduction-to-abduction strength is a predictive test for hip adductor muscle strain. Studies do not agree on whether RoM of the hamstring is a predictive screening tool for groin injury. Body mass index and the age of an athlete could contribute to an ankle sprain. There is support in the literature to suggest that greater strength of the plantar flexors may

be a predictive measure for sustaining an ankle injury. Furthermore, there is some agreement that the measurement of postural sway is a predictive test for an ankle injury.

**Conclusions** The screening tools mentioned above can be recommended to medical staff and coaches for screening their athletes. Future research should focus on prospective studies in larger groups and should follow athletes over several seasons.

## INTRODUCTION

Injuries to the lower extremities are common in team sports such as soccer, basketball, volleyball, football and field hockey.<sup>1-3</sup> For example, an anterior cruciate ligament (ACL) injury is a common injury to the knee in soccer. In female and male soccer players the injury rate per 1000 athlete exposures of ACL injuries is 0.28 and 0.09, respectively.<sup>4</sup> An incidence of 1.6 per 1000 player hours is reported in female handball players,<sup>5</sup> and in soccer players, 14–32% of all acute injuries are knee injuries.<sup>6-11</sup> Hamstring strains occur frequently in Australian football and soccer especially.<sup>8-11</sup> In basketball, soccer and volleyball a large amount of injuries involve ankle sprains.<sup>12</sup>

The personal and professional impairment of athletes caused by injuries can result in high costs for athletes and for society.<sup>13</sup> For instance, a severe knee injury might limit future sport participation. The development of knee osteoarthritis is a long-term consequence of an ACL injury, which can cause permanent disability for the athlete.<sup>14</sup> An ankle sprain on the other hand can result in decreased ankle range of motion (RoM), persistent pain, swelling and chronic ankle instability,<sup>15</sup> whereas a hamstring strain can result in chronic symptoms and reduced performance as well.<sup>16</sup> Another negative consequence of an ACL injury, hamstring injury and an ankle sprain is the chance of re-injury.<sup>16-25</sup> In the US the costs of ACL injuries are estimated at \$US1 billion per year<sup>26</sup> and the cost of treating ankle sprains is estimated at \$US2 billion dollars per year.<sup>27</sup> Considering personal grief, disabling consequences and high costs caused by injuries, the importance of prevention is evident.

Development of screening tools may be a crucial component in preventing lower extremity injuries. Screening tools can be used preseason to identify athletes that are at high risk of developing an injury.<sup>28,29</sup> With this information, training programs can be adjusted to the individual athlete. There is a need for the development of simple, low-cost screening tools, which can be used on a large scale in the clinic or the field.<sup>29</sup> There are numerous studies that have conducted prospective trials to find risk factors for predicting injury in athletes.<sup>16,19,30-43</sup> However, as it is important to know which of these screening tools are indeed reliable, valid and predictive for injury, the purpose of this systematic review was to identify tools for the prevention of lower extremity injuries and describe their reliability, validity, sensitivity and specificity.

## METHODS

### Literature Search

To find articles concerning anthropometric and/or physical screening tools that can predict the proneness of injury in team sports, a systematic literature search was conducted in MEDLINE (1966 to September 2011), EMBASE (1989 to September 2011) and CINAHL (1982 to September 2011). A combination of the following search terms was used: group (i) ‘hip injuries’, ‘knee injuries’, ‘ankle injuries’, ‘lower extremity injuries’, ‘athletic injuries’; group (ii) ‘soccer injuries’, ‘basketball injuries’, ‘volleyball injuries’, ‘hockey injuries’, ‘team sports’, ‘ball sports’; group (iii) ‘anthropometry’, ‘fatigue’, ‘musculoskeletal system’, ‘motor control’, ‘biomechanics’, ‘observational’, ‘joint instability’, ‘kinetics’, ‘core stability’; group (iv) ‘predictive value of tests’, ‘sensitivity and specificity’, ‘reproducibility of results’, ‘reliability’, ‘validity’; and group (v) ‘screening tool’, ‘screening test’, ‘risk factors’, ‘preseason screening’, ‘proneness’, ‘mass screening’, ‘risk assessment’, ‘screening’ and ‘prospective studies’. Within the groups, the search terms were connected with OR and between the groups with AND. In addition, a hand search was done on the reference lists in included articles. The results of the three searches were taken together and duplicates were filtered out. Furthermore, reference lists were screened to find additional articles.

### Literature Selection

The titles and abstracts of the articles that were identified were reviewed by the first author (J.M.D.) for potential relevance. The full text of possibly relevant articles was analyzed by two reviewers for final inclusion (J.M.D. and A.B.), based on the following inclusion criteria: (i) full text; (ii) published in English, German or Dutch; (iii) acute musculoskeletal injuries to lower extremities; (iv) athletes participating in ball team sports; (v) average age of athletes ( $\geq 13$  years); (vi) physical screening tests and/or anthropometry; (vii) reliability, validity, sensitivity or specificity described in numbers; and (viii) predictive value described in numbers.

If disagreements on inclusion were present a third reviewer (K.A.P.M.L.) decided whether the article had to be included or not.

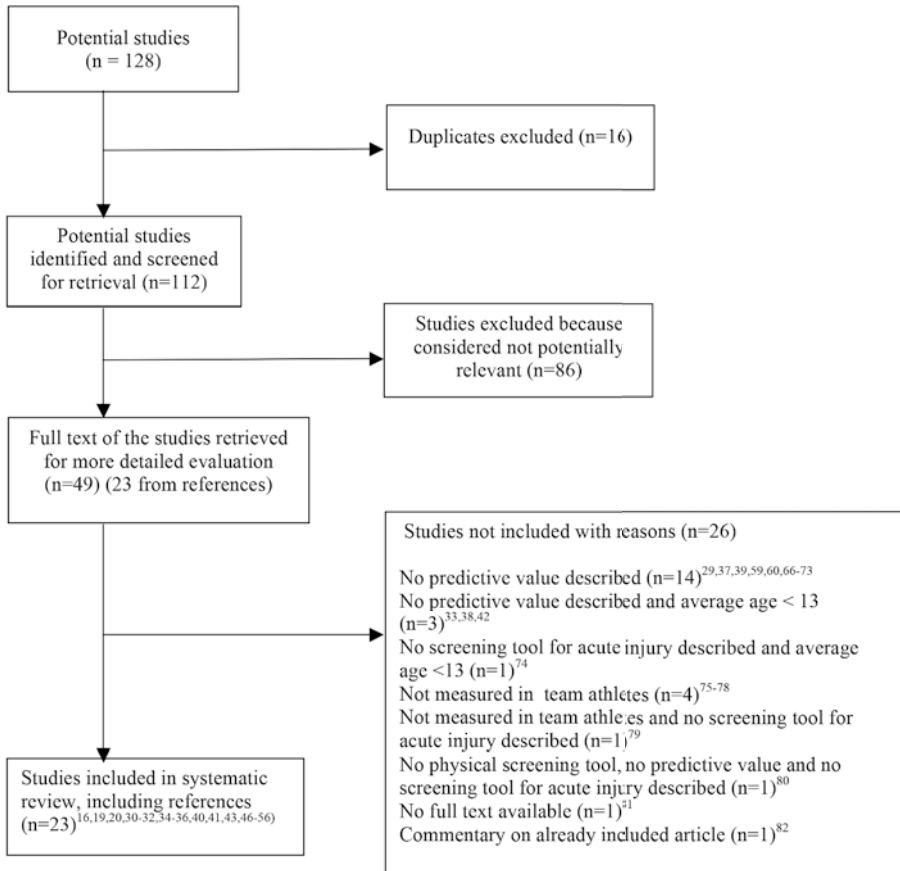
### Data Extraction

Data were extracted by the first author from each included article. The subject characteristics, screening tool, reliability, validity, sensitivity or specificity, outcome

measure, injury definition and measure of association with injury (e.g. odds ratio [OR] or relative risk [RR]) were summarized.

### **Methodological Quality**

To examine the methodological quality, a modified version of the Cochrane Group on Screening and Diagnostic Test Methodology (Cochrane methods) was used.<sup>44</sup> Two authors assessed the quality of the included studies (J.M.D. and A.B.). The first four questions were replaced for a score of level of evidence defined by the Oxford Center for Evidence-Based Medicine.<sup>45</sup> The range of this score was from 1 to 5; 1 was the lowest score and 5 the highest. The design, selection criteria, setting, demographic information, description of the screening tool, reproducibility of the screening tool and percentage missing were used to score methodological quality. Furthermore, items about statistical analysis were added as well as outcome and confounders. The maximal score that could be reached was 16.



**Figure 2.1.** Flow chart of search strategy.

## RESULTS

### Search Findings

Appendix 1 in the Supplement Digital Content (<http://links.adisonline.com/SMZ/A12>) shows a summary of the search strategy and Figure 2.1 shows the flow diagram of the search strategy. The assessment of the methodological quality of the included studies is shown in table 2.1. The mean score was 15.5 (range 13–16). Table 2.1 shows the study characteristics of these studies.



**Table 2.1.** Methodological quality of studies

	Design <sup>a</sup>	Level of evidence <sup>b</sup>	Selection criteria <sup>c</sup>	Setting <sup>d</sup>	Demographic information <sup>e</sup>	Screening tool <sup>f</sup>	Statistical analysis <sup>g</sup>	Reliability of screening test <sup>h</sup>	Percentage missing <sup>i</sup>	Outcome <sup>j</sup>	Confounders <sup>k</sup>	Total score (max = 16)
Plisky et al. <sup>41</sup>	1	5	1	1	0	1	1	1	1	1	1	14
Östenberg et al. <sup>46</sup>	1	5	1	1	1	2	1	1	1	1	0	15
Söderman et al. <sup>47</sup>	1	5	1	1	1	2	1	1	1	1	1	16
Arnason et al. <sup>20</sup>	1	5	1	1	1	2	1	1	1	1	0	15
Myer et al. <sup>36</sup>	1	5	1	1	1	2	1	1	1	1	1	16
Hewett et al. <sup>34</sup>	1	5	1	1	1	2	1	1	1	1	0	15
Smith et al. <sup>48</sup>	1	5	1	1	1	2	1	1	1	1	1	16
Engelbrechtsen et al. <sup>30</sup>	1	5	1	1	0	1	1	0	1	1	1	13
Hrysomallis et al. <sup>49</sup>	1	5	1	1	1	2	1	1	1	1	0	15
Gabbe et al. <sup>40</sup>	1	5	1	1	0	2	0	1	1	1	0	13
Engelbrechtsen et al. <sup>16</sup>	1	5	1	1	0	2	0	1	1	1	1	14
Cameron et al. <sup>50</sup>	1	5	1	1	1	2	1	0	1	1	0	14
Bennell et al. <sup>51</sup>	1	5	1	1	1	2	0	1	1	1	0	14
Bennell et al. <sup>52</sup>	1	5	1	1	1	1	1	?	1	1	0	13
Engelbrechtsen et al. <sup>43</sup>	1	5	1	1	0	2	0	0	1	1	1	13
Emery et al. <sup>53</sup>	1	5	1	1	0	2	1	1	1	1	1	15
Tyler et al. <sup>54</sup>	1	5	1	1	1	2	1	1	1	1	0	15
Pefanis et al. <sup>55</sup>	1	5	1	1	1	2	1	0	1	1	0	14
McGuine et al. <sup>31</sup>	1	5	1	1	1	2	1	1	1	1	0	15
Wang et al. <sup>35</sup>	1	5	1	1	1	2	1	1	1	1	1	16
Hadzic et al. <sup>32</sup>	1	5	1	1	1	2	1	?	1	1	0	14
Engelbrechtsen et al. <sup>19</sup>	1	5	1	1	0	2	1	1	1	1	1	15
Trojan et al. <sup>56</sup>	1	5	1	1	1	2	1	1	1	1	1	16

<sup>a</sup> Prospective (1 point) or retrospective studies (0 point).

<sup>b</sup> Oxford Center for Evidence Based Medicine Levels of Evidence (level 1 = 5 points; level 2 = 4 points; level 3 = 3 points; level 4 = 2 points; level 5 = 1 point).

<sup>c</sup> Inclusion- and exclusion criteria clearly described (1 point).

<sup>d</sup> Enough information to identify setting (1 point).

<sup>e</sup> Age (mean or median and SD or range) and gender reported (1 point).

<sup>f</sup> Description of screening tool had insufficient detail to permit replication of the test. Test device or instruments, protocol of screening tool(s) reported (1 point each).

<sup>g</sup> For variable of interest details given on mean or median, standard deviation or confidence intervals and predictive value (1 point).

<sup>h</sup> Reliability reported (1 point).

<sup>i</sup> All included subjects measured and, if appropriate, missing data or withdrawals from study reported or explained (1 point).

<sup>j</sup> Outcome clearly defined and method of examination of outcome adequate (1 point).

<sup>k</sup> Most important confounders and prognostic factors identified and adequately taken into account in design study (1 point).

### Predictive Tools for Lower Extremity Injury

Some studies analyzed screening tools for lower extremity injury in general (see table 2.2 for definitions of all injuries). The traumatic or acute injuries that were registered in the studies were contusion of the foot, calf, knee or thigh, partial rupture of the plantar aponeurosis, ankle sprain, total rupture of the Achilles tendon, ACL injury, medial collateral ligament injury, lateral collateral ligament injury, hamstring and groin strain,<sup>47</sup> fracture, dislocation, ligament sprain, muscle strain, contusion, tendinitis/bursitis and other type of injuries to the foot, ankle, leg, knee, thigh front, hamstring, groin and back.<sup>46</sup> In one study, the type of injuries were measured but not shown; however, ankle sprain and knee sprain were mentioned as examples of registered injuries.<sup>41</sup> Different screening tests were described to predict injuries to the lower extremities. In soccer players, two studies showed significant predictive values for increased generalized joint laxity (OR 5.3,  $p < 0.00$ ;<sup>46</sup> OR 3.10,  $p = 0.02$ ).<sup>47</sup> General joint laxity was determined as an overall score of joint laxity of the fingers, thumb, elbow, knees and trunk measured using the Beighton method.<sup>46</sup> The star excursion balance test (SEBT) was suggested to predict lower extremity injury in high-school basketball players (OR 2.50;  $p < 0.05$ ) and specifically in girls (OR 6.5;  $p < 0.05$ ).<sup>41</sup> In football, an increasing age placed players at a greater risk of injury to the lower extremities (OR 1.1 per year; 95% CI 1.0, 1.1;  $p = 0.05$ ).<sup>20</sup>

### Predictive Tools for Anterior Cruciate Ligament (ACL) Injury

Multiple significant screening tests were described for measuring the risk for sustaining an ACL injury. It has been shown that risk of an ACL injury could be predicted by hyperextension of the knee (OR 4.78; 95% CI 1.24, 18.44;  $p = 0.02$ ) and side-to-side differences in anterior-posterior tibiofemoral translation (OR 4.03; 95% CI 1.68, 9.69;  $p = 0.00$ ) in female soccer and basketball players.<sup>36</sup>

Knee and hip joint flexion-extension and adduction-abduction on a drop vertical jump task in female basketball and soccer players were analyzed in another study.<sup>34</sup> The most important finding was that knee abduction moment was 2.5-fold greater in ACL-injured athletes ( $p < 0.00$ ) and knee abduction moment predisposed the occurrence of an ACL injury with 73% specificity and 78% sensitivity.<sup>34</sup>

Although the Landing Error Scoring System (LESS) was described as a reliable and valid method,<sup>57</sup> predictive values for ACL injury could not be found in soccer, football, rugby, field hockey, basketball, gymnastics, lacrosse and volleyball players.<sup>48</sup>

**Predictive Tools for Knee Injury**

A definition of knee injury is shown in table 2.2. Two studies described screening tools for knee injuries in general.<sup>30,49</sup> In one study, a clinical examination was performed by male football players.<sup>30</sup> However, none of the measured factors could predict acute knee injuries.<sup>30</sup> Height was a predictive screening tool for knee ligament injuries in Australian football players.<sup>49</sup>

**Predictive Tools for Hamstring Strain**

The included studies used different screening tools and showed mixed results. Three studies measured flexibility of the hamstrings in adult Australian football players but used different tests.<sup>16,40,52</sup> The sit and reach, active knee extension, passive straight leg raise, slump, active hip internal rotation RoM, active hip external rotation, dorsiflexion lunge test, lumbar spine extension RoM and the modified Thomas test were assessed.<sup>40</sup> Furthermore, the toe-touch test, end-range flexion hip, lumbar flexion, ratio lumbar spine and flexion-to-hip flexion were used to measure flexibility,<sup>52</sup> while a clinical examination, which included measuring the hamstring length and the hip RoM, were assessed as well, in combination with a Nordic hamstring strength test.<sup>16</sup> In addition, the thigh muscle strength and isokinetic strength testing of the hamstring and quadriceps muscles of both legs in Australian Rules football players were analysed.<sup>20,51</sup> Age was a significant screening tool for hamstring strains in football players (OR 1.4 [1 year]; 95% CI 1.2, 0.4;  $p < 0.00$ );<sup>20</sup> also, a decreased flexibility of the hamstring and an age older than 23 years were predictive for hamstring injuries in adult football players (RR 0.3; 95%CI 0.1, 0.8;  $p = 0.02$  and RR 3.8; 95% CI 1.1, 14.0;  $p = 0.04$ , respectively).<sup>40</sup> However, flexibility of the hamstring was shown to be not significant as a screening tool in soccer players.<sup>16</sup> Another study also suggested that flexibility cannot predict risk on hamstring strain in Australian Rules football players.<sup>52</sup> The hamstring/quadriceps ratio (H : Q) was a significant predictor of a hamstring strain in Australian football players (area = 0.87,  $p = 0.01$ , 95% CI 0.71, 1.03; area = 0.88,  $p = 0.01$ , 95% CI 0.73, 1.03, respectively).<sup>50</sup>

Table 2.2. Study characteristics of the studies included

Study	Subject characteristics <sup>a</sup>	Screening tool	Outcome measure	Reliability	Injury definition	Study results
<b>Lower extremity</b>						
Plisky et al. <sup>41</sup>	130 M; 105 F, High-school basketball players, 9 <sup>th</sup> to 12 <sup>th</sup> graders	SEBT	Reach distance (average of right and left limb in cm), right/left reach distance difference (cm) and composite reach distance (%)	Intratester reliability: anterior reach (ICC 0.84; 95% CI 0.68, 0.92); posteromedial reach (ICC 0.82; 95% CI 0.65, 0.91); posterolateral reach (ICC 0.87; 95% CI 0.75, 0.94); Limb length ICC 0.99; 95% CI 0.98, 0.99) ICC (pre- and post-season measurement) anterior reach (ICC 0.89; 95% CI 0.80, 0.94); posteromedial reach (ICC 0.93; 95% CI 0.87, 0.96); posterolateral reach (ICC 0.91; 95% CI 0.84, 0.95)	Injury defined as injury to the limb, including hip, but not the lumbar spine or sacroiliac joint, that resulted from a team-sponsored basketball practice or game that caused restricted participation or inability to participate in the current or next scheduled practice or game	Significant risk factors for injuries: anterior right/left reach distance > 4 cm (OR 2.50; $p < 0.05$ ) and composite reach distance < 4.0% of limb length in girls (OR 6.5; $p < 0.05$ )
Östenberg and Roos <sup>46</sup>	123 (32 elite; 91 non-elite) F senior soccer players, 20.7 ± 4.6 y, 14–39 y	<ul style="list-style-type: none"> <li>• Isokinetic knee muscle strength at 60 and 180°/s</li> <li>• One-leg-hop</li> <li>• Vertical jump</li> <li>• Square-hop</li> <li>• Continuous MFT</li> <li>• BMI</li> <li>• General joint laxity</li> </ul>	<ul style="list-style-type: none"> <li>• Strength (Peak torque (Nm) and total work (J))</li> <li>• One-leg-hop (cm)</li> <li>• Vertical jump (cm)</li> <li>• Square-hop (m)</li> <li>• Aerobic capacity (<math>\text{VO}_{2\text{max}}</math>)</li> <li>• BMI (<math>\text{kg}/\text{m}^2</math>)</li> <li>• General joint laxity (yes/no)</li> </ul>	<ul style="list-style-type: none"> <li>• Good reliability</li> <li>• Good reliability</li> <li>• Inter- and intrareliability: <math>r = 0.94</math> respectively <math>r = 0.74</math></li> <li>• Correlates to <math>\text{VO}_{2\text{max}}</math></li> </ul>	Injury was registered if it resulted in an absence from scheduled activities for at least one practice or game. All injuries were registered	Significant risk factors for injuries: increased general joint laxity (OR 5.3; $p < 0.00$ ), high performance in the functional test square-hop (OR 4.3; $p = 0.00$ ), and age over 25 years (OR 3.7; $p < 0.01$ )
Söderman et al. <sup>47</sup>	146 F soccer players, 20.6 ± 4.7 y	<ul style="list-style-type: none"> <li>• Clinical examination: general joint laxity (passive hyper-extension fingers, passive apposition of thumb, hyper-extension elbow, hyper-extension knee, dorsiflexion ankle), Lachman test and the varus and valgus laxity, ankle dorsiflexion and hamstring flexibility</li> </ul>	<ul style="list-style-type: none"> <li>• General joint laxity (score 1–10) and flexibility (°)</li> </ul>	<ul style="list-style-type: none"> <li>• Knee joint laxity: Good intra- and interreliability</li> <li>• Flexometer: ICC 0.87–0.99</li> </ul>	Athlete was defined injured until she was able to return to full activity in games and/or practice sessions	Generalized joint laxity (OR 3.10; 95% CI 1.19, 8.01; $p = 0.02$ ), low postural sway of the legs (OR 0.46; 95% CI 0.22, 0.96; $p = 0.04$ ), hyperextension of the knee joint (OR 2.50; 95% CI 1.11, 5.61; $p = 0.03$ ) and a lower H : Q ratio during concentric action (OR 0.95; 95% CI 0.89, 0.999; $p = 0.05$ ) significantly increased the risk of traumatic leg injuries

Table 2.2. Continued.

Study	Subject characteristics <sup>a</sup>	Screening tool	Outcome measure	Reliability	Injury definition	Study results
Amason et al. <sup>20</sup>	306 M football players (Icelandic elite league and first division), 24 y, 16–38 y	• Isokinetic measurements of quadriceps and hamstring torques	• Strength (Nm/kg), H : Q ratio (%)	• Biodex: ICC 0.95–0.98 (concentric); 0.73–0.89 (eccentric). Kin-Comdynamometer: good reproducibility	A player was defined as injured if he was unable to participate in a match or a training session because of an injury that occurred in a football match or during training. The player was defined as injured until he was able to play a match or comply fully with all instructions given by the coach, including sprinting, turning, shooting, and playing football at full tempo	Multivariate logistic regression: hyperextension of the knee joint (OR 3.84; 95% CI 1.51, 9.78; p = 0.01), low postural sway (OR 0.31; 95% CI 0.13, 0.70; p = 0.01), a lower H : Q ratio (OR 0.93; 95% CI 0.88, 0.99; p = 0.02) significantly increased the risk of traumatic leg injury
		• Testing of postural sway of the legs	• Postural sway (BI)	• Test-retest 10° decrease on 1 day		
		• $VO_{2peak}$	• $VO_{2peak}$ (ml/kg/min)			In general older players were at higher risk of injury (OR 1.1 per year; 95% CI 1.0, 1.1; p = 0.05).
		• Body composition	• Body composition (% fat) and BMI (kg/m <sup>2</sup> )	• Commonly accepted formulas		
		• Power testing	• Power (maximal average [W])	• Intrarater reliability CV 4 – 6%		
		• Jump tests (SJ, CMJ, CMJ-I)	• Jump tests (cm)	• Intrarater reliability SJ CV 4.3% for SJ; CV 5.3% CMJ		
		• Flexibility tests (static RoM for hamstrings, adductors, rectus femoris, and hip flexors)	• Flexibility (sum in ° and °)	• Intrarater reliability CV 0.9 – 3.5%		
		• Ankle and knee stability tests (ankle: anterior drawer and talar tilt tests for lateral stability and a medial stability test; knee: Lachmann test, valgus test for medial stability, and posterior drawer test)	• Stability (stable/unstable)			

Table 2.2. Continued.

Study	Subject characteristics <sup>a</sup>	Screening tool	Outcome measure	Reliability	Injury definition	Study results
<b>ACL</b>						
Myer et al. <sup>36</sup>	1558 F soccer and basketball players 16.3 ± 1.7 vs 15.6 ± 1.4 y	• Generalized joint-laxity tests (fifth-finger hyperextension >90°, elbow hyperextension beyond normal, wrist and thumb to forearm and knee hyper-extension beyond neutral) • AP tibiofemoral translation	• Joint laxity (°)  • AP displacement (mm)	• Good to excellent interrater reliability  • ICC between testers 0.81 – 0.86; ICC within testers 0.92 – 0.95; intrarater reliability ICC 0.89 – 0.97	ACL rupture	Univariable logistic regression: risk factors of ACL injury: side-to-side differences in knee laxity (OR 3.23; 95% CI 1.47, 7.08; p = 0.00)  Multivariable logistic regression: risk factors of ACL injury: hyperextension knee (OR 4.78; 95% CI 1.24, 18.44; p = 0.02) and side-to-side differences in AP tibiofemoral translation (OR 4.03; 95% CI 1.68, 9.69; p = 0.002).
Hewett et al. <sup>34</sup>	205 F soccer, basketball and volleyball players, (injured vs uninjured) 15.8 ± 1.0 vs 16.1 ± 1.7 y	Drop vertical jump task: • Knee joint flexion-extension and adduction-abduction	• Knee abduction-adduction and flexion-extension moment (Nm) and knee abduction angle (°)	Within session reliability ICC > 0.93	ACL injury defined as ACL rupture that occurred during a game or practice of their competitive season	Knee abduction angle (p < 0.05) at landing 8° greater in ACL injured. ACL-injured athletes had a 2.5 times greater knee abduction moment (p < 0.001) and 20% higher ground reaction force (p < 0.05), stance time 16% shorter (p < 0.01). Side-to-side knee abduction moment was significant predictor of ACL injury (OR 6.4; p < 0.00)
		• Hip flexion-extension and adduction-abduction	• Hip abduction-adduction and flexion-extension moment (Nm) and hip abduction angle (°)			Knee abduction moment predicted ACL injury status with 73% specificity and 78% sensitivity regression (knee abduction angles, knee abduction moments, side-to-side differences) showed a predictive r <sup>2</sup> of 0.88

Table 2.2. Continued.

Study	Subject characteristics <sup>a</sup>	Screening tool	Outcome measure	Reliability	Injury definition	Study results
Smith et al. <sup>48</sup>	Soccer, football, rugby, field hockey, basketball, gymnastics, lacrosse and volleyball players 20 M; 44 F; 18 ± 2y	Drop vertical jump according to LESS protocol	LESS score	Interrater reliability ICC 0.84 SEM 0.71 Intrater reliability ICC 0.91 SEM 0.42	A noncontact ACL injury mechanism was defined by our group as an event with no direct contact to the ACL-injured knee from another athlete, the ground, or extra-neous structure	No relation between LESS score and sustaining an ACL injury
<b>Knee</b>						
Engelbretsen et al. <sup>30</sup>	508 M football players (amateur teams) 24.0 y ± 4.2, 16.2–37.7	• Clinical examination	• Knee axis (normal, genu varum, genu valgus), RoM flexion and extension (°), Lachman test (positive/negative), anterior and posterior drawer (positive/negative), valgus and varus stress tests in extension and 30° of flexion (positive/negative)	Intertest reliability κ = 1.00	Injury defined as a physical complaint sustained by a player that resulted from a football match or football training, forcing the player to miss or being unable to take full part in future training or match play ("time-loss" injury) Acute injuries defined as injuries with a sudden onset associated with a known trauma. An injury was classified as a knee injury if it was recorded as an acute injury of the knee ligaments, menisci, bone or joint cartilage, or if haemarthrosis had occurred as a result of knee sprain.	Univariate analysis: any findings at clinical examination (OR 2.62; 95% CI 1.03, 6.68; p = 0.04), flexion contraction in range of motion testing (OR 0.96; 95% CI 0.93, 1.00; p = 0.05) and varus stress tests in full extension (OR 8.50; 95% CI 1.85, 39.0; p < 0.01) and 30° flexion (OR 5.69; 95% CI 1.73, 18.8; p < 0.01) were significant risk factors for acute knee injury Multivariate analysis: none of these factors were associated with an increased acute knee injury risk
Hrysomallis et al. <sup>49</sup>	210 AFL players, 22.9 ± 3.8 y, 17.2–33.7 y	• Stepping balance test  • Height and weight	• Balance score (mean balance score of both limbs and right-left limb balance difference)  • Height (cm) and weight (kg)	• ICC 0.80	A knee or ankle ligament injury was recorded if diagnosed by medical personnel and if it caused the athlete to cease participation in the current session and precluded participation in the next official training session or game	Height of the player could significantly predict a knee ligament injury (OR 3.93; CI 3.03, 14.90; p < 0.05)

Table 2.2. Continued.

Study	Subject characteristics <sup>a</sup>	Screening tool	Outcome measure	Reliability	Injury definition	Study results
<b>Hamstring</b>						
Gabbe et al. <sup>40</sup>	126 adult Australian football players (community level)	<ul style="list-style-type: none"> <li>• Sit and reach</li> <li>• Active knee extension</li> <li>• Passive straight leg raise</li> <li>• Slump</li> <li>• Active hip internal rotation RoM</li> <li>• Active hip external rotation</li> <li>• Dorsiflexion lunge test</li> <li>• Lumbar spine extension RoM</li> <li>• Modified Thomas test</li> </ul>	Flexibility (°)	Inter-rater ICC 0.88–0.97 Test-retest reliability ICC 0.63–0.99	Hamstring injury that fulfilled criteria: sudden onset posterior thigh pain, tenderness on palpation, with or without pain on stretch of hamstring muscle and with or without pain on contraction of the hamstring muscle group	Increased age ( $\geq 23$ y) was associated with increased risk of hamstring injury (RR 3.8; 95% CI 1.1, 14.0; $p = 0.04$ ); decreased hamstring flexibility (RR 0.3; 95% CI 0.1, 0.8; $p = 0.02$ ) could significantly predict the time for sustaining a hamstring injury
Engebretsen et al. <sup>16</sup>	508 M soccer players (Norwegian 1st, 2nd and 3rd division) injured group: mean $\pm$ SEM: $24.8 \pm 0.6$ ; non-injured group mean $\pm$ SEM: $23.9 \pm 0.2$ (no mean age of the whole group of athletes was described)	<ul style="list-style-type: none"> <li>• Nordic hamstring strength test</li> <li>• Clinical examination</li> </ul>	<ul style="list-style-type: none"> <li>• Nordic hamstring strength test (strong/weak?)</li> <li>• Hamstring length (°), hip RoM (°), tender on palpation of hamstrings, iliopsoas and psoas major muscles (yes/no)</li> </ul>	<ul style="list-style-type: none"> <li>• Intertest reliability <math>\kappa = 0.24</math></li> <li>• Hamstring length CV 9.1 %</li> </ul>	Injury defined as any physical complaint sustained by a player that made him seek medical assistance and that resulted from a soccer match or soccer training, forcing him to miss or being unable to take full part in future soccer training or match play. Acute injuries defined as injuries with a sudden onset associated with a known trauma	None of the physical tasks predicted hamstring injury
Cameron et al. <sup>50</sup>	20 M Australian football players (professional AFL team), $23.6 \pm 3.2$ y	<ul style="list-style-type: none"> <li>• Thigh muscle strength</li> </ul>	<ul style="list-style-type: none"> <li>• Relative peak torques (Nm/kg)</li> </ul> <p>H : Q ratio (%)</p>		Hamstring injury had to satisfy criteria: acute onset of pain in the posterior thigh during training or match, posterior thigh pain reproduced with stretch, contraction an palpation of the hamstring muscle, hamstring muscle injury demonstrated by MRI, at least one match missed due to hamstring injury	H : Q ratio (area 0.88, $p = 0.01$ ; 95% CI 0.73, 1.03) was significant predictor of hamstring injury



Table 2.2. Continued.

Study	Subject characteristics <sup>a</sup>	Screening tool	Outcome measure	Reliability	Injury definition	Study results
Bennell et al. <sup>51</sup>	102 M senior Australian Rules footballers (professional AFL and A-grade amateur level), 22.2 ± 3.6 y	Isokinetic strength testing of the hamstring and quadriceps muscles of both legs	Absolute concentric and eccentric peak torque (Nm) H : Q ratio (%)		Hamstring muscle strain had to fulfill criteria: sudden onset of pain in the hamstring muscle during a match or training, pain in the hamstring muscle when muscle contracts and with stretching, tenderness to palpation, caused the player to miss an official match	No significant difference between hamstring injured or injured players for any of the variables measured, with no variable to predict the likelihood of injury (p > 0.05)
Bennell et al. <sup>52</sup>	67 Australian Rules footballers 22.7 ± 3.44y, 18–31 y	<ul style="list-style-type: none"><li>• Toe-touch test</li><li>• End range flexion hip</li><li>• Lumbar flexion</li><li>• Ratio lumbar spine</li><li>• Flexion to hip flexion</li></ul>	Flexibility (°)	Relation between TTD and hip excursion r <sup>2</sup> = 0.71	Hamstring muscle strain had to fulfill criteria: sudden onset of pain in the hamstring muscle during a match or training, pain in the hamstring muscle when muscle contracts and with stretching, tenderness to palpation, caused the player to miss an official match	No significant difference between hamstring injured or injured players for any of the variables measured, with no variable to predict the likelihood of injury (p > 0.05)
Arason et al. <sup>20</sup>	306 M football players (Icelandic elite league and first division) 24y, 16–38 y	<ul style="list-style-type: none"><li>• VO2peak</li><li>• Body composition</li><li>• Power testing</li><li>• Jump tests (SJ, CMJ, CMJ one)</li><li>• Flexibility tests (static RoM for hamstrings, adductors, rectus femoris, and hip flexors)</li><li>• Ankle and knee stability tests (ankle: anterior drawer and talar tilt tests for lateral stability and a medial stability test; knee: Lachmann test, valgus test for medial stability, and posterior drawer test)</li></ul>	<ul style="list-style-type: none"><li>• VO2peak (mL/kg/min)</li><li>• Body composition (%) fat and BMI (kg/m<sup>2</sup>)</li><li>• Power (maximal average [W])</li><li>• Jump tests (cm)</li><li>• Flexibility (sum in ° and °)</li><li>• Stability (stable/unstable)</li></ul>	<ul style="list-style-type: none"><li>• Commonly accepted formulas</li><li>• Intratester reliability CV 4 – 6%</li><li>• Intratester reliability SJ CV 4.3% for SJ; CV 5.3% CMJ</li><li>• Intratester reliability CV 0.9 – 3.5%</li></ul>	A player was defined as injured if he was unable to participate in a match or a training session because of an injury that occurred in a football match or during training. The player was defined as injured until he was able to play a match or comply fully with all instructions given by the coach, including sprinting, turning, shooting, and playing football at full tempo	The significant risk factor for hamstring strains was age (OR 1.4 [1 y]; 95% CI 1.2, 0.4; p < 0.00)

Table 2.2. Continued.

Study	Subject characteristics <sup>a</sup>	Screening tool	Outcome measure	Reliability	Injury definition	Study results
Groin						
Engelbretsen et al. <sup>43</sup>	508 M soccer players (Norwegian 1st, 2nd and 3rd division) injured group mean $\pm$ SEM: $24.8 \pm 0.6$ ; uninjured group and injured group mean $\pm$ SEM: $23.9 \pm 0.2$ (no mean age of the whole group of athletes was described)	<ul style="list-style-type: none"><li>• Isometric adductor strength</li></ul>	<ul style="list-style-type: none"><li>• Strength (weak or not weak)</li></ul>	<ul style="list-style-type: none"><li>• Intertest reliability CV 19.6%</li></ul>	Injury defined as any physical complaint sustained by a player that made him seek medical assistance and that resulted from a soccer match or soccer training, forcing him to miss or being unable to take full part in future soccer training or match play. Acute injuries defined as injuries with a sudden onset associated with a known trauma. An injury was classified as a groin injury if it was recorded as either an acute or an overuse injury of the inside thigh/groin area	Risk of groin injury. Multivariate analysis (only acute injuries): Isometric adductor strength was not a significant predictor
Emery et al. <sup>53</sup>	1292 NHL players	<ul style="list-style-type: none"><li>• Peak isometric adductor torque</li><li>• Active hip abduction measurements</li></ul>	<ul style="list-style-type: none"><li>• Torque (Nm)</li><li>• Flexibility (°)</li></ul>	<ul style="list-style-type: none"><li>• Test-retest reliability ICC 0.95</li><li>• Intrarater reliability ICC 0.89 – 0.99; interrater reliability ICC 0.80 – 0.92</li></ul>	Injury defined as a muscle strain injury involving a muscle in any of the abdominal, hip flexor, or hip adductor muscle groups. Abdominal and inguinal hernias were included. Injury reported if player missed next day's session	Peak isometric adductor torque and total abduction flexibility were not predictive of injury

Table 2.2. Continued.

Study	Subject characteristics <sup>a</sup>	Screening tool	Outcome measure	Reliability	Injury definition	Study results
Arnason et al. <sup>20</sup>	306 M football players (Ice-landic elite league and first division) 24 y, 16–38 y	<ul style="list-style-type: none"> <li>• <math>\dot{V}O_{2peak}</math></li> <li>• Body composition</li> <li>• Power testing</li> <li>• Jump tests (SJ, CMJ, CMJ 1)</li> <li>• Flexibility tests (static RoM for hamstrings, adductors, rectus femoris, and hip flexors)</li> <li>• Ankle and knee stability tests (ankle: anterior drawer and talar tilt tests for lateral stability and a medial stability test; knee: Lachmann test, valgus test for medial stability, and posterior drawer test)</li> </ul>	<ul style="list-style-type: none"> <li>• <math>\dot{V}O_{2peak}</math> (mL/kg/min)</li> <li>• Body composition (%) and BMI (kg/m<sup>2</sup>)</li> <li>• Power (maximal average [W])</li> <li>• Jump tests (cm)</li> <li>• Flexibility (sum in ° and °)</li> <li>• Stability (stable/unstable)</li> </ul>	<ul style="list-style-type: none"> <li>• Commonly accepted formulas</li> <li>• Intrarater reliability CV 4–6%</li> <li>• Intrarater reliability SI CV 4.3% for SJ; CV 5.3% CMJ</li> <li>• Intrarater reliability CV 0.9–3.5%</li> </ul>	<p>A player was defined as injured if he was unable to participate in a match or a training session because of an injury that occurred in a football match or during training. The player was defined as injured until he was able to play a match or comply fully with all instructions given by the coach, including sprinting, turning, shooting, and playing football at full tempo</p>	Decreased RoM in hip abduction (OR 0.90 [1°; 95% CI 0.8, 1.0; $p = 0.05$ ) was a significant risk factor for groin strains
Tyler et al. <sup>54</sup>	81 M professional ice hockey players 23 ± 4.3 y	<ul style="list-style-type: none"> <li>• Hip flexion, abduction and adduction strength</li> <li>• Hip adductor and hip flexor flexibility</li> </ul>	<ul style="list-style-type: none"> <li>• Strength (N) and hip adduction-abduction strength ratio</li> <li>• Flexibility (°)</li> </ul>	<p>Test-retest reliability ICC 0.84 – 0.99</p>	<p>Injury defined as any event that kept a player out of a practice or a game or required the attention of the team physician. An adductor muscle strain was defined as pain on palpation of the adductor tendons or the insertion on the pubic bone, or both, and groin pain during adduction against resistance.</p>	Hip adduction-to-abduction strength ratio was the best predictor of a future adductor strain (RR = 17 [based on a hip adduction of <80% of abduction strength]; $p = 0.00$ )

Table 2.2. Continued.

Study	Subject characteristics <sup>a</sup>	Screening tool	Outcome measure	Reliability	Injury definition	Study results
<b>Ankle</b>						
Pefanis et al. <sup>55</sup>	45 M basketball, soccer and volleyball athletes (national and international experience) 23.15 ± 3.67 y	<ul style="list-style-type: none"> <li>• Quadriceps angle</li> <li>• BMI</li> </ul>	<ul style="list-style-type: none"> <li>• Flexibility (°)</li> <li>• BMI (kg/m<sup>2</sup>)</li> </ul>		Ankle sprain is the injury of ankle joint occurring during sports participation (training or game) leading to immediate cessation of sporting activity with at least 1 abstention from sports (game or training)	Q angle was statistically nonsignificant in predicting ankle strain ( $p > 0.10$ ) BMI ( $p < 0.10$ ) and age ( $p < 0.10$ ) contributed more to an ankle sprain
McGuine et al. <sup>31</sup>	119 M, 16.1 ± 1.1 y; 91 F, 16.3 ± 1.3 y high-school basketball players	Unilateral ankle tests	COG sway velocity (°S/S)	ICC (compilation score) 0.88	Ankle sprain injury defined as trauma that disrupts the structures of the ankle that occurs during a team-sponsored practice or competition session, and causes the athlete to miss the rest of practice or competition or miss next scheduled team practice or competition	Higher postural sway scores corresponded to increased ankle sprain injury rates (OR 10.2; $p = 0.00$ )
Wang et al. <sup>35</sup>	42 high-school basketball players 16.5 – 1.1 y	<ul style="list-style-type: none"> <li>• Isokinetic ankle strength</li> <li>• 1-legged standing Performance</li> <li>• Ankle ROM</li> </ul>	<ul style="list-style-type: none"> <li>• Standardized strength (ft-lb/lb of weight)</li> <li>• Variation in postural sway (mm)</li> <li>• Flexibility (°),</li> <li>• Eversion/inversion ratio (%), endurance index (%)</li> </ul>	ICC 0.81–0.96  • Acceptable retest reliability 0.66–0.85 • ICC 0.78–0.94	Ankle sports injury defined as an incident or period occurring in connection with basketball during training or competition, which occurs at the ankle, handicaps the player during performance or completely prevents the player from playing, or makes the player seek treatment to continue playing basketball  Time loss definition, all injuries that caused a player to miss a match or training session were registered	High variation in anteroposterior and mediolateral directions corresponded to occurrences of ankle injuries (OR 1.22; $p = 0.01$ ; OR 1.22; $p < 0.00$ )
Hadzic et al. <sup>32</sup>	38 M professional volleyball players (Slovenian divisions I and II) 21 ± 5y, 15–34 y	<ul style="list-style-type: none"> <li>• Isokinetic ankle strength</li> <li>• Postural dynamic balance testing</li> </ul>	<ul style="list-style-type: none"> <li>• Strength (Nm)</li> <li>• Postural sway (overall stability index, anterior-posterior stability index, medial-lateral stability index)</li> <li>• Flexibility (°)</li> </ul>			Greater strength of plantar flexors (OR 1.22; 95% CI 1.04, 1.43; $p < 0.05$ ) and decreasing RoM in dorsiflexion (OR 0.63; 95% CI 0.41; 0.97) are significant risk factors for the ankle

Table 2.2. Continued.

Study	Subject characteristics <sup>a</sup>	Screening tool	Outcome measure	Reliability	Injury definition	Study results
Engelbrechtsen et al. <sup>19</sup>	508 M soccer players (Norwegian 1st, 2nd and 3rd division) (mean $\pm$ SEM): 24.0 $\pm$ 0.2; injured athletes group (mean $\pm$ SEM): 24.0 $\pm$ 0.6 (no mean age of the whole group of athletes was described)	<ul style="list-style-type: none"> <li>Balance tests</li> <li>Clinical testing</li> </ul>	<ul style="list-style-type: none"> <li>Balance (score 1-5)</li> <li>Clinical testing: foot type (normal, pes planus, pes cavus, played forefoot), standing rearfoot alignment (normal, valgus), hallux position (normal, valgus), anterior drawer (normal, pathologic), RoM supination and pronation (<math>^{\circ}</math>)</li> </ul>	<ul style="list-style-type: none"> <li>Interobserver reliability <math>\kappa = 0.40</math></li> <li>Anterior drawer <math>\kappa = 0.45</math>; foot type <math>\kappa = 0.84</math>; standing rearfoot <math>\kappa = 0.91</math>; hallux position <math>\kappa = 1.00</math>; toe deformity <math>\kappa = 1.00</math></li> </ul>	Injury defined as any physical complaint sustained by a player that made him seek medical assistance and that resulted from a soccer match or soccer training, forcing him to miss or being unable to take full part in future soccer training or match play. Acute injuries defined as injuries with a sudden onset associated with a known trauma	Univariate analysis and multivariate analysis: none of the physical tests was a candidate risk factor for ankle injury
Trojian et al. <sup>26</sup>	180 high-school university athletics and intercollegiate athletics 18.4 $\pm$ 2.2y, 14–21 y	SLB test	Balance/ postural sway (positive/negative)	<ul style="list-style-type: none"> <li>Intrater reliability <math>\kappa = 0.90</math></li> </ul>	An ankle sprain injury was defined as trauma that disrupted the structures of the ankle and which occurred during a team sponsored practice or competition session, and caused the athlete to miss the rest of practice or competition, or miss the next scheduled team practice or competition.	A positive SLB test was predictive of an ankle sprain (OR 2.54; 95% CI 1.02, 6.03) After controlling for gender, sport, school, previous history of ankle sprain, and taping (OR 2.54; 95% CI 1.02, 6.03; $p < 0.05$ )
Hrysomalilis et al. <sup>49</sup>	210 AFL players 22.9 $\pm$ 3.8 y, 17.2–33.7 y	<ul style="list-style-type: none"> <li>Stepping balance test</li> <li>Height and weight</li> </ul>	<ul style="list-style-type: none"> <li>Balance score (mean balance score of both limbs and right-left limb balance difference)</li> <li>Height (cm) and weight (kg)</li> </ul>	<ul style="list-style-type: none"> <li>ICC 0.80 95% CI 0.56, 0.92</li> </ul>	<ul style="list-style-type: none"> <li>A knee or ankle ligament injury was recorded if diagnosed by medical personnel and if it caused the athlete to cease participation in the current session and precluded participation in the next official training session or game</li> </ul>	<ul style="list-style-type: none"> <li>An above average mean balance score of both limbs was a significant predictor for ankle ligament injury (OR 2.44; 95% CI 1.91, 7.48; <math>p &lt; 0.05</math>)</li> </ul>

<sup>a</sup> Ages are presented in actual, mean age  $\pm$  SD and ranges where stated.

ACL = anterior cruciate ligament; AFL = Australian Football League; AP = anterior-posterior; BI = balance index; BIP = body inertia propensity; BMI = body mass index; CMI = countermovement jump; CMI-1 = one-leg countermovement jump; COG = center of gravity; CV = coefficient of variance; F = female; H/Q = hamstrings/quadriceps ratio; ICC = intraclass correlation coefficient; J = joules; LESS = Landing Error Scoring System; M = male; MFT = multistage fitness test; MRI = magnetic resonance imaging; NHL = National Hockey League; Nm = Newton meters; OR = odds ratio; RoM = range of motion; RR = relative risk; SEBT = star excursion balance test; SEM = standard error of the mean; SJ = standing jump; SLB = single leg balance test; S/S = degrees of sway per second; TTD = toe-touch distance; VO2max = maximal oxygen uptake; VO2peak = peak oxygen uptake; W = watts.

### Predictive Tools for Groin Injury

The definition of groin injury is described in table 2.2. Screening tools to predict groin injuries were analyzed in soccer,<sup>43</sup> football<sup>20</sup> and hockey players.<sup>53,54</sup> Hip adduction-to-abduction strength ratio was a significant predictor of a future adductor strain (RR 17 [based on a hip adduction of <80% of abduction strength];  $p = 0.00$ ).<sup>54</sup> Furthermore, a decreased RoM of hip abduction for groin strains was a predictive screening tool for a groin injury (OR 0.9 [1°]; 95% CI 0.8, 1.0;  $p = 0.05$ ).<sup>20</sup>

From the literature, it was not clear as to whether hip flexibility was a significant screening tool for groin injuries.<sup>20,53,54</sup>

### Predictive Tools for Ankle Sprain

The definition of ankle sprain for each of the included studies is described in table 2.2. A high variation in postural sway (anteroposterior and mediolateral direction) was shown to be predictive for ankle injuries in male high-school basketball players (OR 1.22,  $p = 0.01$ ; OR 1.22,  $p < 0.00$ ).<sup>35</sup> Furthermore, a greater postural sway measured with unilateral ankle tests showed significant predictive values in high-school basketball players (OR 10.2;  $p = 0.00$ ).<sup>31</sup> The unilateral ankle test was a modified Romberg test on a force platform and the compilation sway score on this test was an indication of overall ability to balance.<sup>31</sup> In high-school, university and intercollegiate athletics postural sway measured by a positive single leg balance (SLB) test was predictive of an ankle sprain after controlling for gender, sport, school, previous history of ankle sprain and taping (OR 2.54; 95% CI 1.02, 6.03;  $p < 0.05$ ).<sup>56</sup> In Australian football players, an above average mean balance score of both limbs was a significant predictor for ankle ligament injury (OR 2.44; 95% CI 1.91, 7.48;  $p < 0.05$ ).<sup>49</sup> No significant predictive values for postural sway were measured in volleyball players.<sup>32</sup>

The included studies also showed different results for RoM as a screening test. In soccer players (supination OR 1.21,  $p = 0.15$ ; pronation OR 0.98,  $p = 0.95$ ; dorsiflexion OR 0.94,  $p = 0.79$ )<sup>19</sup> and in basketball players (knee extended  $p = 0.71$ ; knee flexed  $p = 0.30$ ) the RoM of the ankle was not a predictive screening task.<sup>31</sup> However, in volleyball players, the RoM in dorsiflexion was shown as a significant screening tool (OR 0.63; 95% CI 1.04, 1.43;  $p < 0.05$ ).<sup>32</sup> Body mass index (BMI) and age contributed to an ankle injury in basketball, volleyball and soccer athletes ( $p < 0.10$ ).<sup>55</sup>

## DISCUSSION

The main purpose of this systematic review was to illustrate the predictive values for injury of lower extremity tests and to select screening tests that can be used in the clinic or field to identify athletes at risk of injury to the lower extremities. In addition, the reliability, validity, sensitivity and specificity of these tests was described. The main findings of our review show that, per body part, several screening tools are available to identify athletes at risk for injury.

### Methodological Quality

The mean score on the modified Cochrane methods scoring list was 15.5 (range 13–16). All studies showed high scores. Approximately half of the studies did not describe the most important confounders and how they were taken into account. In addition, some studies showed a lack of demographic information, a lack of detailed description of screening tool to allow replication of the test, statistical analysis, reliability of the screening tool and definition of outcome. No specific checklist for this current topic of interest was available to the knowledge of the authors; therefore, a combination of items from the Cochrane and Oxford Center for Evidence-based Medicine checklists was made.<sup>44</sup> These checklists are well reported and accepted for use in methodological quality assessments.

### Predictive Tools for Lower Extremity Injury

One study showed the SEBT was reliable and predictive of lower extremity injury in high school basketball players.<sup>41</sup> Data were collected during one basketball season, therefore it might be difficult to generalize these results; however, the results of this study are promising.

In female senior soccer players, general joint laxity, a high performance in the functional test square hop and an age over 25 years were predictive for leg injuries.<sup>46</sup> Moreover, the square hop test showed an acceptable reliability. Although reliability of general joint laxity was not reported in this study, another study showed good reliability of this screening tool;<sup>27</sup> however, the ORs were significant but considering the skewness of the distributions of elite and non-elite players, no conclusions could be made.<sup>46</sup> Furthermore, hyperextension of the knee joint, a low postural sway, side-to-side differences in hamstring flexibility and ankle dorsiflexion can cause a greater risk of traumatic leg injuries in female soccer players.<sup>47</sup> Taking the reliability of the measurements into account, postural sway was the only screening test that was not

reliable. In summary, there was agreement that general joint laxity was a predictive measure for injuries to the lower extremities.

It is not clear from these studies what type of specific injury the measures are exactly related to. This makes it difficult to conclude which screening tools are related to which injury. It is therefore difficult to make recommendations on screening tests that should be used by trainers in the field.

An increasing age was an indicator for being more susceptible to injury to the lower extremities in football players.<sup>20</sup> A limitation of this study was that minor injuries could have been underestimated due to injury registration problems. However, the most important limitation was that only 50% of the athletes completed all of the tests; consequently, the results of this study should be interpreted with care.

Studies on the reliability of screening tools that described no prospective relation to injury were not included in this review because of the inclusion and exclusion criteria used. Before a screening tool can be used in a prospective cohort design, reliability of the tool should be analyzed. Therefore, we do want draw attention to this aspect, as these studies provide valuable information for future research. One study measured the inter- and intrarater reliability of nine screening tests, included in a test battery, in male elite soccer players.<sup>2</sup> The included tests were the deep squat test, one-legged squat test, inline lunge test, active hip flexion test, straight leg raise test, push-up test and diagonal lift test. The intrarater reliability of this test battery was good on both occasions (intraclass correlation coefficient [ICC] 0.80 and ICC 0.81). There were no significant differences between the test occasions ( $p = 0.31$ ) and between the raters at the two test occasions, indicating good inter-rater reliability.<sup>2</sup> In Australian football clubs the inter-rater and test-retest reliability of lower extremity musculoskeletal screening tests were examined.<sup>28</sup> The sit and reach, active knee extension, passive straight leg raise, slump, active hip internal RoM, active hip external RoM, lumbar spine extension RoM and the modified Thomas test were evaluated. The interrater reliability of all tests was very good to excellent (ICC 0.88–0.97). Furthermore, the tests demonstrated a good test-retest reliability (ICC 0.63–0.99).<sup>28</sup> Another study analyzed the inter- and intraobserver reliability of the modified Thomas test, hip internal and external rotation, combined elevation, ankle dorsiflexion lunge, bridging hold, prone four-point hold and calf heel raises.<sup>29</sup> The tests in general showed a poor interobserver reliability, four of ten tests had an ICC above 0.80 (ICC 0.27–0.99), and a higher intrarater reliability, nine tests scored an ICC above 0.80 (ICC 0.56–0.99).<sup>29</sup> Because the reliability of this test battery is not satisfactory, care must be taken in using it in prospective design studies to find screening tools for injuries to the lower extremities.



Based on this review, there is some support in the literature to suggest that general joint laxity is a predictive measure for leg injuries. The anterior right/left reach distance  $>4$  cm and the composite reach distance  $<4.0\%$  of limb length in girls measured with the SEBT may predict leg injuries. Furthermore, an increasing age, a lower H : Q ratio, and a decreased RoM of hip abduction may predict the occurrence of leg injuries. All these screening tools can be recommended to medical staff and coaches.

### **Predictive Tools for ACL Injury**

Different tests were suggested as predictive measures for an ACL injury. Knee hyperextension and side-to-side differences in anterior-posterior tibiofemoral translation were shown as significant and reliable screening tools for ACL injury.<sup>36</sup> These results are difficult to generalize, because confounding variables were not taken into account.

Measuring neuromuscular control and joint load was a good and reliable tool to predict ACL injury risk in soccer, basketball and volleyball.<sup>34</sup> That is, an increased valgus motion and valgus moments at the knee joint during the impact phase of jump landing tasks were able to predict ACL injury in female athletes. Hewett et al.<sup>34</sup> admit that there are confounding variables and although they describe the neuromuscular parameters as the most important determinant for an ACL injury, generalizability is still a problem in this study.

Generalized joint laxity was a significant predictor for an ACL injury (RR 2.8) in another large prospective study that was excluded due to our criteria.<sup>58</sup> This is in agreement with Myer et al.<sup>36</sup> Furthermore, a small femoral notch width and, in women, a higher than normal BMI (RR 2.0) and KT-2000 arthrometer values that were 1 standard deviation or more above the mean were shown as significant screening tools in military recruits.<sup>58</sup> The presence of more than one of these screening tools greatly increased the RR of ACL injury. These results indicate that, potentially, these screening tests can be used in team sport athletes as well.

The reliability and validity of screening tests for ACL injury is analyzed by a few studies that were excluded in this review, since they did not describe a predictive value. In basketball players, a two dimensional (2D) video analysis showed a good correlation to excessive knee valgus on a sidestep ( $r^2 = 0.58$ ) and a side jump task ( $r^2 = 0.64$ ).<sup>59</sup> Another study also found correlates to laboratory-based measures, which could predict a high knee valgus with 73% sensitivity and 70% specificity in female basketball and soccer players.<sup>42</sup> Although knee valgus moment is predictive for an ACL injury,<sup>34</sup> Myer et al.<sup>42</sup> and McLean et al.<sup>59</sup> showed no direct relation between

a 2-D video analysis and an ACL injury. Acceptable rater and inter-rater reliability (kappa [k] value 0.75–0.85) and specificity (60–72%) of observational risk screening was shown; however, sensitivity values were insufficient (67–87%).<sup>60</sup> Sensitivity had a priority over specificity in this study; consequently, the desired level of sensitivity was 80% or higher, and that of specificity 50% or higher.<sup>60</sup> This explains why sensitivity values were indicated as insufficient. The inter-rater reliability and the criterion validity of the LESS were measured as well.<sup>57</sup> The LESS is a jump-landing assessment tool and a screening tool to identify athletes at potential risk for ACL injury. The inter-rater item reliability between expert rater versus novice rater showed moderate to excellent k values (0.46–0.88).<sup>57</sup> The overall LESS score showed a good reliability (ICC 0.84;  $p < 0.001$ ). Furthermore, the validity of the LESS was moderate to excellent.<sup>57</sup> However, it should be mentioned that only a significant phi correlation between LESS scores and 3-D scores was found for the item knee valgus RoM.<sup>57</sup> Although other measured items showed no significant phi correlation between LESS scores and 3D scores, they showed moderate to excellent agreement (84–100%).<sup>57</sup> In middle- and high-school soccer and basketball players the reliability of 3-D motion analysis was studied.<sup>61</sup> Kinematic and kinetic variables were measured during landing in young athletes. Most of these variables showed an excellent to good reliability (ICC 0.75–0.96).<sup>61</sup> These results suggest that this screening tool might help in identifying potential mechanisms related to injury risk factors.<sup>61</sup> In summary, the LESS score and landing 3-D motion analysis are reliable tools.

What is of note, is that two of three studies regarding ACL injury risk factors included in this systematic review examined female athletes only. Although female athletes are at a greater risk of sustaining an ACL injury, the risk for male athletes should not be neglected. The number of male athletes that sustain an ACL injury is still certainly high.<sup>62</sup>

Based on this review, hyperextension of the knee, side-to-side differences in anterior-posterior knee laxity and differences in knee abduction moment between both legs, are suggested to be predictive tests for sustaining an ACL injury and can be recommended to medical staff and coaches.

### **Predictive Tools for Knee Injury**

A large cohort study on screening tests for acute knee injuries showed that a simple screening test such as a clinical examination, was not able to predict acute knee injuries in male football players, also, reliability of the clinical examination was analyzed before using it in a prospective design ( $k = 1.00$ ).<sup>30</sup> Possibly, more advanced screening tests should be able to predict acute knee injuries. Acute knee injuries

included dislocations, meniscus tears, cartilage lesions and sprains.<sup>30</sup> In addition, in Australian football players, height was suggested to be predictive,<sup>49</sup> more specifically, taller players were at risk of injury; however, injury rate could have been underestimated. Moreover, the power of the study was not enough to identify a small-to-medium effect.<sup>49</sup>

Based on this review, measuring height can be recommended as a screening tool for knee ligament injury.

### **Predictive Tools for Hamstring Strain**

An age older than 23 years and the flexibility of the hamstring were shown to be reliable predictors for hamstring injury in Australian football players.<sup>40</sup> The RR was measured instead of OR. Considering the small number of observed hamstring injuries ( $n = 20$ ), the power of the study was not high, therefore no causality between screening tests and injuries could be determined.<sup>40</sup> Additionally, age was a significant predictor of a hamstring injury in football players.<sup>20</sup> Considering the limitations of this study, the results should be interpreted with care. The study of Engebretsen et al.<sup>16</sup> was comparable in design with other studies on screening tools for acute knee injuries, groin injuries and acute ankle injuries.<sup>19,30,43</sup> The screening tasks used in this study (Nordic hamstring strength test and clinical examination) were not able to identify the athletes at risk of hamstring injury in male football players. The clinical examination included testing the hamstring flexibility using the passive knee extension test and, in this case, measurements of hamstring flexibility were not able to predict a hamstring injury in contrary to the results of Gabbe et al.<sup>40</sup> Furthermore, flexibility of the hamstring measured by the toe-touch test was not able to predict the occurrence of a hamstring injury.<sup>52</sup> It may be that the toe-touch test is not the most valid method to measure risk of a hamstring injury, because it measures flexibility in end range. A second limitation of the study was that only a small number of hamstring strains occurred, resulting in low power.<sup>52</sup>

In one study, there was no significant relation between H : Q strength ratio and hamstring injury shown.<sup>51</sup> This study only compared injured and non-injured athletes and looked at significant differences;<sup>51</sup> therefore, no conclusions can be made about the risk of sustaining groin injuries; further research is needed in this area. In contrary to the study of Bennell et al.,<sup>51</sup> a low H : Q ratio significantly predicted hamstring injury in Australian football players.<sup>50</sup> Although not reported in this study, reliability can be assumed and was supported in previous studies.<sup>63</sup> In the study of Cameron et al.,<sup>50</sup> areas under the receiving operating characteristic (ROC) curves were calculated. When the area value was higher than 0.8, a test had good predictive

power. The H : Q ratio showed a value above 0.8 of the area under the ROC curve (0.88). These researchers recommended the use of the thigh muscle strength test to predict risk of hamstring injury in the field.<sup>50</sup>

In conclusion, based on this review, there is some evidence to suggest that an increase of age is an indicator for sustaining a hamstring injury and this should be recommended to medical staff and coaches. However, debate exists in the analyzed literature that the flexibility of the hamstring, as well as the H : Q ratio, should be used as predictive screening tools also.

### **Predictive Tools for Groin Injuries**

Isometric testing of the adductor muscles was not able to predict acute groin strains in soccer players.<sup>43</sup> In addition, the intertest reliability of this test was poor. However, it should be noted that only 22 acute time-loss injuries were reported, therefore the results should be interpreted with caution.<sup>43</sup> This study differed from the study of Engbretsen et al.,<sup>16</sup> as all groin injuries were included. This could potentially explain the differences in results between the studies.

A second study found that peak isometric torque and total abduction (sum of unilateral measurements) flexibility could not predict groin injuries in ice-hockey players.<sup>53</sup> Considering the fact that a selection bias may have occurred that caused an underestimation of the relation between peak isometric torque and total abduction flexibility and groin injuries, no conclusions can be made.<sup>53</sup>

Hip adduction-to-abduction strength was a reliable test and could predict hip adductor muscle strain in ice-hockey players.<sup>54</sup> However, in this study, only eight athletes with hip adductor muscle strains were registered; consequently, the results should be taken with care.

In football, decreased RoM in hip abduction showed sufficient reliability and was a significant screening test for groin strains.<sup>20</sup> Considering the limitations of this study, these results should also be interpreted with care.

In summary, based on this review, hip-adduction-to-abduction strength is a predictive test for hip adductor muscle strain. Studies do not agree on whether RoM of the hamstring is a predictive screening tool for groin injury.

### **Predictive Tools for Ankle Sprain**

In male basketball, soccer and volleyball athletes it was suggested that a Q-angle test was not able to predict an ankle sprain injury.<sup>55</sup> No controlling for confounding variables was performed in this study, therefore results should be used carefully.<sup>55</sup>

Measuring balance prior to season could predict the chance of ankle sprain injury in high school male and female basketball players.<sup>31</sup> The reliability of balance measurement tools was measured in this study and the test-retest reliability showed varying ICC's (0.42–0.88).<sup>31</sup> The compilation score was the most reliable (0.88) and, consequently, this score was used to measure postural sway in this study.<sup>31</sup> However, this score described an overall balance ability, so further research is necessary to develop a reliable and valid method to measure postural sway in individual limbs. A high variation of postural sway in anteroposterior and mediolateral directions showed an acceptable reliability and could partly predict the increased risk of ankle injury in basketball players; nevertheless, it is important to note that the ORs were relatively low (OR 1.22,  $p < 0.00$ ; OR 1.22, respectively).<sup>35</sup> This study did take confounding variables into account. The one-legged standing test used in this study could be used by basketball trainers to predict which athletes are at risk of an ankle injury.<sup>35</sup> Furthermore, postural sway measured by the SLB test could predict ankle sprain in high-school university and intercollegiate athletics. The confounding variables gender, sport, school, previous history of ankle sprain and taping were taken into account.<sup>56</sup> Moreover, the SLB test was shown to be a reliable test and the inter-rater reliability was good ( $k = 0.90$ ;  $p < 0.00$ ).<sup>56</sup> In contrary to the findings in other included studies, the postural sway of professional volleyball players, measured by postural dynamic balance testing, was not identified as a significant screening tool.<sup>32</sup>

Five of the included studies measured postural sway; however, as explained, different methods are used. This could explain the inconsistent findings. Four studies showed postural sway as a predictive test for ankle injury<sup>31,35,49,56</sup> and one study did not.<sup>32</sup>

Ankle plantar flexion strength and a decreased dorsiflexion RoM predicted an ankle sprain injury in volleyball players.<sup>32</sup> Acceptable reliability of the Biodex Stability System (BSS) was shown in earlier studies.<sup>64</sup> Limitations of this study were a small sample size ( $n = 38$ ) and eccentric strength of the plantar and dorsal flexors were not measured. Measuring the eccentric strength of the plantar and dorsal flexors could help in predicting the risk on ankle sprains;<sup>32</sup> hence, in future research, the predictive value of eccentric strength should possibly be evaluated.

In Australian football players, an above average mean balance score of both limbs was a reliable and significant predictor for ankle ligament injury.<sup>49</sup>

Although studies that described reliability but showed no predictive value of a screening tool were not included, it is important to mention that the test-retest reliability of ankle injury risk factors was analysed.<sup>27</sup> Generalized joint laxity, ankle ligamentous stability and ankle strength were suggested as reliable measures in

healthy college age athletes and were measured before and after the season ( $r > 0.75$ ;  $p < 0.05$ ). However, RoM measurements were not reliable.<sup>27</sup>

Based on this review, the BMI and age of an athlete could contribute to an ankle sprain. There is support in the literature to suggest that the higher strength of the plantar flexors may be a predictive measure for sustaining an ankle injury. Furthermore, there is some agreement that the measurement of postural sway is a predictive measure for an ankle injury.

## LIMITATIONS

This systematic review provides a good overview of the predictive values of simple screening tools that are presently described in the literature; however, there are some limitations that need to be addressed.

First, there was a variety of tasks, playing levels of sport, age and type of team sports included in this review. Also, studies with both male and female athletes were included. This makes it difficult to compare the results and to make recommendations; consequently, further research should focus on measuring predictive values of promising screening tools. In addition, other populations, for example in other sports and age groups, should be evaluated. Screening in younger age groups, especially, has the potential for being effective in reducing injuries in team sports. Furthermore, most of the studies with the purpose of finding significant screening tools for an ACL injury are performed in female athletes. However, it is important that predictive values of screening tools for ACL injury in male athletes be examined also.

Second, studies that require more extensive methods of screening, such as 3-D motion analysis, were included also, as they can support more simple tasks. For example, Myer et al.<sup>38</sup> developed an algorithm to use in the field to predict ACL injuries, as a result, no laboratory tests will be necessary. A suggestion for future research is to analyze the prospective relationship of this algorithm with ACL injury.

There is a need for more prospective studies in the future. Ideally, they should involve large sample groups and should follow athletes over several seasons. In this way, better recommendations can be made to trainers and coaches. In future research it is also important to focus on the development of simple, reliable and valid screening tools.

## CONCLUSION AND PRACTICAL IMPLICATIONS

Based on this review, several screening tools for injuries to the ACL, knee, hamstring, groin and ankle can be recommended for use in the field. For injuries in general, there is some support in the literature to suggest that general joint laxity is a predictive measure for leg injuries. The anterior right/left reach distance  $>4$  cm and the composite reach distance  $<4.0\%$  of limb length in girls measured with the SEBT may predict leg injuries. Furthermore, an increasing age, a lower H : Q ratio, and a decreased RoM of hip abduction may predict the occurrence of leg injuries. Hyperextension of the knee, side-to-side differences in anterior-posterior knee laxity and differences in knee abduction moment between both legs are suggested to be predictive tests for sustaining an ACL injury and height was a predictive screening tool for knee ligament injuries. There is some evidence that when age increases the probability of sustaining a hamstring injury increases. Debate exists in the analyzed literature as to whether measurement of the flexibility of the hamstring and the H:Q ratio are suitable for predictive screening tools. Hip-adduction-to-abduction strength is a predictive test for hip adductor muscle strain. Studies do not agree on whether RoM of the hamstring is a predictive screening tool for groin injury. BMI and the age of an athlete could contribute to an ankle sprain. There is support in the literature to suggest that the higher strength of the plantar flexors may be a predictive measure for sustaining an ankle injury. Furthermore, there is some agreement that the measurement of postural sway is a predictive test for an ankle injury. These screening tools can be implemented in injury prevention programs. Medical staff and coaches can perform preseason screening by using one or more screening tools to predict which athletes have a greater risk of sustaining an injury to the lower extremities. The next step is to provide an individual training program for the athletes at risk.

Screening tools can be divided into different groups the first being anthropometric tests. Age, BMI and height are often described as predictive screening tools. An advantage of these types of measurement is that they are easy to use by medical staff, coaches and trainers; on the other hand, age and height are not modifiable. However, it might alert coaches to the need of a prevention program for their athletes who are of an increased age and taller than average. BMI on the other hand is a modifiable factor, therefore, collaboration with a dietitian should be part of a regular training program especially in professional athletes. The second group of screening tests measure the flexibility or RoM; for example, the RoM of hip abduction is predictive for injury to the leg in general. Flexibility of joints can easily be measured with the use of a goniometer or an inclinometer.<sup>28</sup> Consequently, medical staff and

coaches can integrate these kind of screening tools in their preseason screening. Furthermore, the third group of screening tests measure strength. H:Q ratios and strength of the plantar flexors are examples of predictive tests. To optimally measure strength, more extensive measurement tools are necessary, such as the Cybex dynamometer or the Biodex dynamometer.<sup>46,47</sup> These tools seem most appropriate for use in a clinical setting; a good alternative could be a handheld dynamometer. Balance measurements are the next group of screening tools. This group can be divided into tools that are easy to perform in the field, such as the SLB and the balance test, and tools that require more extensive equipment, i.e. force plates, such as the one-legged standing performance and unilateral ankle tests. Finally, there is a group of screening tests that are predictive for ACL injury, which include side-to-side differences in anterior posterior knee laxity and knee abduction moment between both legs and require the use of a CompuKT knee arthrometer or specialized software.<sup>34,36</sup> Consequently, these screening tools might not be easily applicable in the field. Currently, researchers are trying to develop applicable screening tools such as the knee abduction moment algorithm and the LESS real time.<sup>33,42,65</sup>

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## Appendix 1.

Search strategy (September 2011)		
MEDLINE <sup>a</sup>	CINAHL <sup>b</sup>	EMBASE <sup>c</sup>
# 1 1 OR 2 OR 3 OR 4 OR 5 OR 6 OR 7 OR 8 OR 9 OR 10 OR 11	1 OR 2 OR 3 OR 4 OR 5 OR 6 OR 7 OR 8 OR 9 OR 10 OR 11	1 OR 2 OR 3 OR 4 OR 5 OR 6 OR 7 OR 8
# 2 12 OR 13 OR 14 OR 15 OR 16 OR 17	12 OR 13 OR 14 OR 15 OR 16 OR 17 OR 18 OR 19 OR 20 OR 21 OR 22	11 OR 12 OR 13 OR 14 OR 15 OR 16 OR 17 OR 18
# 3 18 OR 19 OR 20 OR 21 OR 22 OR 23 OR 24 OR 25 OR 26 OR 27 OR 28 OR 29	23 OR 24 OR 25 OR 26 OR 27 OR 28 OR 29 OR 30 OR 31 OR 32 OR 33 OR 34	19 OR 20 OR 21 OR 22 OR 23 OR 24 OR 25 OR 26 OR 27 OR 28 OR 29 OR 30 OR 31 OR 32 OR 33
# 4 30 OR 31 OR 32 OR 33 OR 34 OR 35 OR 36	35 OR 36 OR 37 OR 38 OR 39 OR 40	34 OR 35 OR 36 OR 37 OR 38 OR 39 OR 40
# 5 37 OR 38 OR 39 OR 40 OR 41 OR 42 OR 43 OR 44 OR 45 OR 46	41 OR 42 OR 43 OR 44 OR 45 OR 46 OR 47 OR 48	41 OR 42 OR 43 OR 44 OR 45 OR 46 OR 47 OR 48 OR 49 OR 50
((# 1 AND # 2) AND # 3 AND (# 4 AND # 5))	((# 1 AND # 2) AND # 3 AND (# 4 AND # 5))	((# 1 AND # 2) AND # 3 AND (# 4 AND # 5))

<sup>a</sup> 1 = "hip injuries" [MeSH]; 2 = "hip injur\*" [TI, AB]; 3 = "knee injuries" [MeSH]; 4 = "knee injur\*" [TI, AB]; 5 = "ankle injuries" [MeSH]; 6 = "ankle injur\*" [TI, AB]; 7 = "lower extremity/ injuries" [MeSH]; 8 = "leg injuries" [MeSH]; 9 = "leg injur\*" [TI, AB]; 10 = "athletic injuries" [MeSH]; 11 = "athletic injur\*" [TI, AB]; 12 = "soccer/ injuries" [MeSH] and [TI, AB]; 13 = "basketball/ injuries" [MeSH] and [TI, AB]; 14 = "volleyball/ injuries" [MeSH] and [TI, AB]; 15 = "hockey/ injuries" [MeSH] and [TI, AB]; 16 = "team sports" [TI, AB]; 17 = "ball sports" [TI, AB]; 18 = "anthropometry" [MeSH]; 19 = "fatigue/prevention and control" [MeSH]; 20 = "fatigue/physiology" [MeSH]; 21 = "musculoskeletal systems" [MeSH]; 22 = "neuromuscular control" [TI, AB]; 23 = "motor control" [TI, AB]; 24 = "biomechanics" [MeSH]; 25 = "biomechanic\*" [TI, AB]; 26 = "observational " [TI, AB]; 27 = "joint instability" [TI, AB]; 28 = "kinetics" [MeSH]; 29 = "core stability" [TI, AB]; 30 = "predictive value of tests" [MeSH]; 31 = "sensitivity and specificity" [MeSH]; 32 = "specific\*" [TI, AB]; 33 = "sensitivity" [TI, AB]; 34 = "reproducibility of results" [MeSH]; 35 = "reliab\*" [TI, AB]; 36 = "valid\*" [TI, AB]; 37 = "screening tool" [TI, AB]; 38 = "screening test" [TI, AB]; 39 = "risk factors" [MeSH]; 40 = "risk factor\*" [TI, AB]; 41 = "pre-season screening" [TI, AB]; 42 = "proneness" [TI, AB]; 43 = "mass screening" [MeSH]; 44 = "risk assessment" [MeSH] and [TI, AB]; 45 = "screening" [TI, AB]; 46 = "prospective studies" [MeSH].

<sup>b</sup> 1 = exp. "hip injuries"/ all SH; 2 = "hip injur\*" in ti, ab; 3 = exp. "knee injuries"/ all SH; 4 = "knee injur\*" in ti, ab; 5 = exp. "ankle injuries"/ all SH; 6 = "ankle injur\*" in ti, ab; 7 = exp. "leg injuries"/ all SH; 8 = "leg injur\*" in ti, ab; 9 = exp. "lower extremity"/ all SH; 10 = exp. "athletic injuries"/ all SH; 11 = "athletic injur\*" in ti, ab; 12 = exp. "soccer injuries"/ all SH; 13 = "soccer injur\*" in ti, ab; 14 = exp. "basketball injuries"/ all SH; 15 = "basketball injur\*" in ti, ab; 16 = exp. "volleyball injuries"/ all SH; 17 = "volleyball injur\*" in ti, ab; 18 = exp. "hockey injuries"/ all SH; 19 = "hockey injur\*" in ti, ab; 20 = exp. "team sports"/ all SH; 21 = "team sports" in ti, ab; 22 = "ball sports" in ti, ab; 23 = exp. "anthropometry"/ all SH; 24 = exp. "muscle fatigue"/ all SH; 25 = exp. "musculoskeletal system"/ all SH; 26 = musculoskeletal system physiology; 27 = exp. "neuromuscular control"/ all SH; 28 = "neuromuscular" in ti, ab; 29 = exp. "biomechanics"/ all SH; 30 = "biomechanic\*" in ti, ab; 31 = "motor control" in ti, ab; 32 = exp. "observational methods"/ all SH; 33 = exp. "joint instability" in ti, ab; 34 = "core stability" in ti, ab; 35 = exp. "predictive value of tests"/ all SH; 36 = exp.

**Appendix 1.** Continued.

“sensitivity and specificity”/all SH; 37 = “specific\*” in ti, ab; 38 = “sensitiv\*” in ti, ab; 39 = exp. “reproducibility of results”/all SH; 40 = exp. “reliability and validity”/all SH; 41 = “screening tool” in ti, ab; 42 = “screening test” in ti, ab; 43 = exp. “risk factors”/all SH; 44 = “proneess” in ti, ab; 45 = “pre-season screening” in ti, ab; 46 = “screening” in ti, ab; 47 = exp. “risk assessment”/all SH; 48 = exp. “prospective studies”/all SH.

c 1 = exp. “hip injury”/all SH; 2 = “hip injur\*” in ti, ab; 3 = exp. “knee injury”/all SH; 4 = “knee injur\*” in ti, ab; 5 = exp. “ankle injury”/all SH; 6 = “ankle injur\*” in ti, ab; 7 = exp. “leg injury”/all SH; 8 = “leg injur\*” in ti, ab; 9 = exp. “sport injury”/all SH; 10 = “sport injur\*” in ti, ab; 11 = “soccer injur\*” in ti, ab; 12 = exp. “basketball”/all SH; 13 = “basketball injur\*” in ti, ab; 14 = exp. “volleyball”/all SH; 15 = “volleyball injur\*” in ti, ab; 16 = “hockey injur\*” in ti, ab; 17 = exp. “team sport”/all SH; 18 = “ball sport\*” in ti, ab; 19 = exp. “anthropometry”/all SH; 20 = exp. “exhaustion” (SH); 21 = exp. “muscle fatigue” (SH); 22 = exp. “musculoskeletal system”/all SH; 23 = “musculoskeletal” in ti, ab; 24 = exp. “neuromuscular system”/all SH; 25 = “neuromuscular” in ti, ab; 26 = exp. “motor control”/all SH; 27 = exp. “biomechanics”/all SH; 28 = “biomechanic\*” in ti, ab; 29 = exp. “observational method”/all SH; 30 = “observational” in ti, ab; 31 = exp. “joint laxity”/all SH; 32 = exp. “kinematics”/all SH; 33 = exp. “kinetics”/all SH; 34 = exp. “prediction and forecasting”/all SH; 35 = exp. “sensitivity and specificity”/all SH; 36 = “specific\*” in ti, ab; 37 = “sensitiv\*” in ti, ab; 38 = exp. “reproducibility”/all SH; 39 = exp. “reliability”/all SH; 40 = exp. “validity”/all SH; 41 = “screening tool” in ti, ab; 42 = exp. “screening test”/all SH and ti, ab; 43 = exp. “risk factor”/all SH and ti, ab; 44 = “proneess” in ti, ab; 45 = “pre-season screening” in ti, ab; 46 = exp. “anonymous screening” (SH); 47 = exp. “developmental screening” (SH); 48 = “screening” in ti, ab; 49 = exp. “risk assessment”/all SH and ti, ab; 50 = exp. “prospective study”/all SH and ti, ab.

Note: CINAHL = Cumulative Index to Nursing & Allied health Literature; exp. = search term exploded to include all narrower terms; MeSH = medical subject headings; TI, AB = title and abstract; SH = subheading(s).

